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NASA TN D-1614

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N63-13791
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TECHNICAL NOTE

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EXPERIMENTAL INVESTIGATION OF THE DYNAMIC STABILITY OF A TOWED PARAWING GLIDER MODEL

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON March 1963

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SUMMARY

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An investigation of the dynamic stability characteristics of a towed parawing glider has been made in the Langley full-scale tunnel by means of free-flight model tests. The model was tested in its basic configuration (wing, risers, and a steel weight representing a payload) and with various amounts of vertical side area added in the plane of symmetry beneath the wing.

The investigation showed that the basic configuration had unsatisfactory tow characteristics because of a large, constant-amplitude lateral oscillation which seemed to consist of a large amount of sidewise motion in proportion to the roll and yaw. It was found that the addition of vertical side area could provide satisfactory tow characteristics if the area was properly located. It should be pointed out that in this investigation the model did not have a cargo package of any appreciable dimensions and, therefore, only the aerodynamics of the wing and vertical panels were involved. For other configurations a somewhat different arrangement of side area might be necessary to achieve satisfactory tow.

INTRODUCTION

The use of towed gliders for transporting troops and material has been the subject of much study for a number of years. In practice it has generally been found necessary for the towed vehicle to be piloted because of difficulty in achieving an inherently stable tow configuration. Inasmuch as use of the parawing as an unmanned cargo-carrying towed glider is being studied by the military, an investigation is being conducted by the National Aeronautics and Space Administration in an effort to determine a satisfactory tow configuration.

The tow tests of the investigation were conducted in the Langley full-scale tunnel to determine the dynamic stability characteristics of a towed parawing model. A simple model in which the cargo was simulated by a steel weight suspended by rigid members below the wing was used in this study. The effects of various changes in geometry, which were achieved by adding vertical side area in the plane of symmetry below the keel, were investigated during the program. Static force tests were made in a low-speed tunnel with a 12-foot octagonal test section at the Langley Research Center over an angle-of-attack range from 20° to 40° in order to determine the static stability characteristics of the various configurations.

SYMBOLS

All lateral data are referred to the body system of axes (fig. 1) and the longitudinal data are referred to the wind axes. All coefficients are based on the flat pattern area of 17.7 square feet, a keel length of 5.0 feet, and a span of 7.1 feet. The moments are referred to the reference center-of-gravity position.

b	wing span (flat pattern), ft
l_k	keel length, ft
F_D	drag force, lb
F_Y	side force, lb
I_X, I_Y, I_Z	moment of inertia about X-, Y-, and Z-axis, respectively, slug-ft^2
F_L	lift force, lb
L/D	lift-drag ratio
M_X	rolling moment, ft-lb
M_Y	pitching moment, ft-lb
M_Z	yawing moment, ft-lb
q	free-stream dynamic pressure, lb/sq ft
S	wing area, sq ft
X,Y,Z	coordinates axes
α	angle of attack of keel, deg
β	angle of sideslip, deg or radians
C_D	drag coefficient, F_D/qS

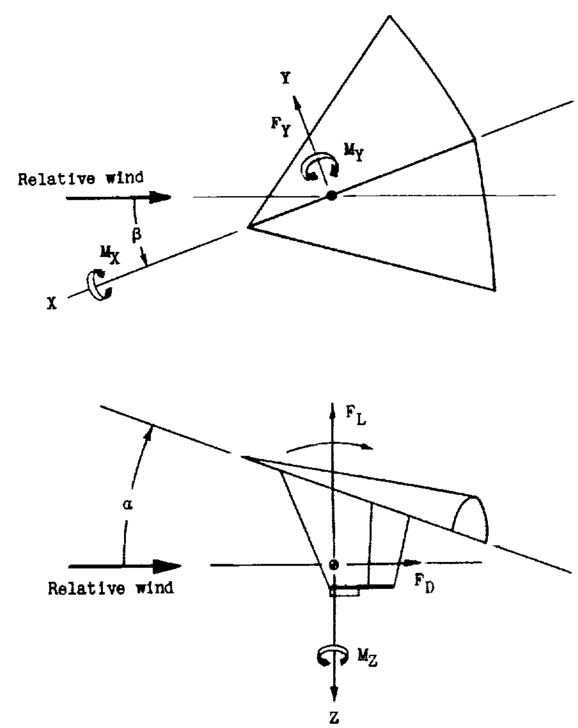


Figure 1.- Sketch of axis systems used in investigation. Arrows indicate positive directions of forces, moments, and angles.

C_L lift coefficient F_L/qS

C_l rolling-moment coefficient, M_X/qSb

C_m pitching-moment coefficient, M_Y/qSl_k

C_n yawing-moment coefficient, M_Z/qSb

C_Y side-force coefficient, F_Y/qS

$C_{l_\beta} = \frac{\partial C_l}{\partial \beta}$ per deg

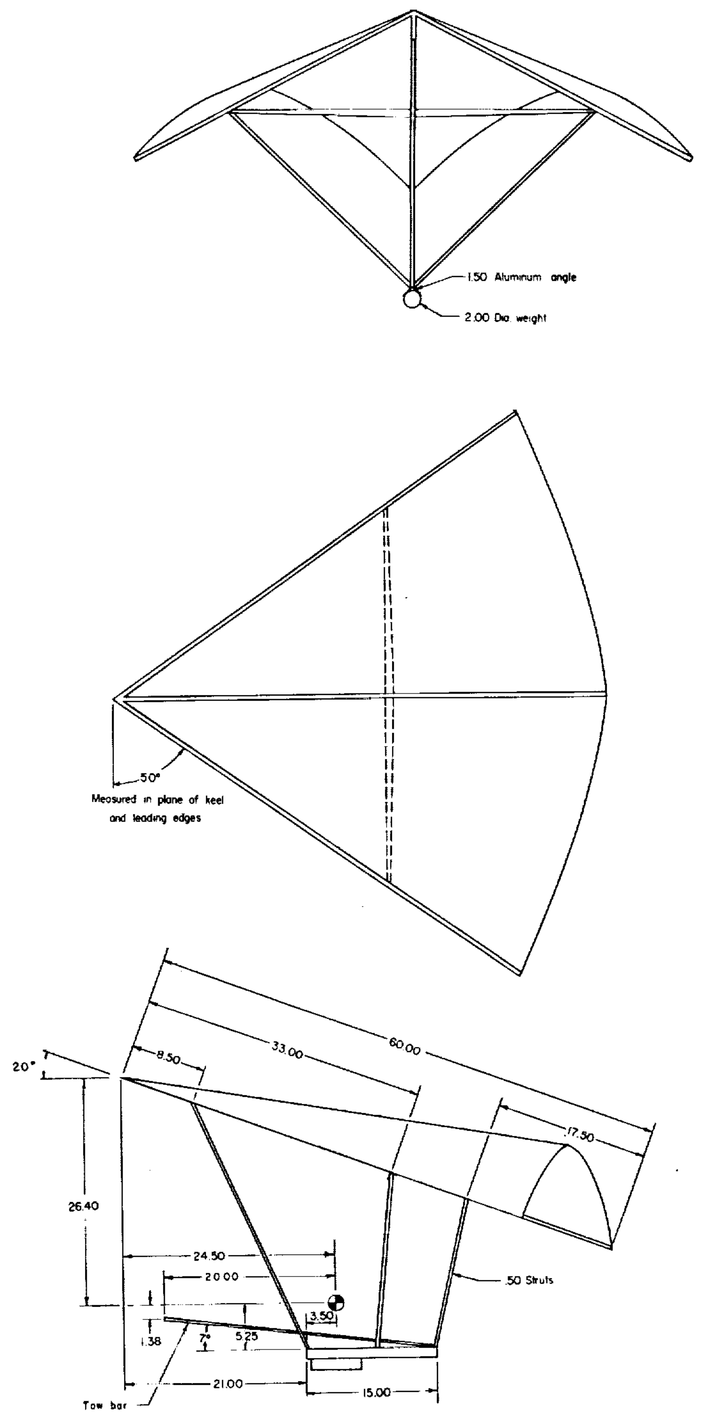
$C_{n_\beta} = \frac{\partial C_n}{\partial \beta}$ per deg

$C_{Y_\beta} = \frac{\partial C_Y}{\partial \beta}$ per deg

APPARATUS AND TESTING TECHNIQUE

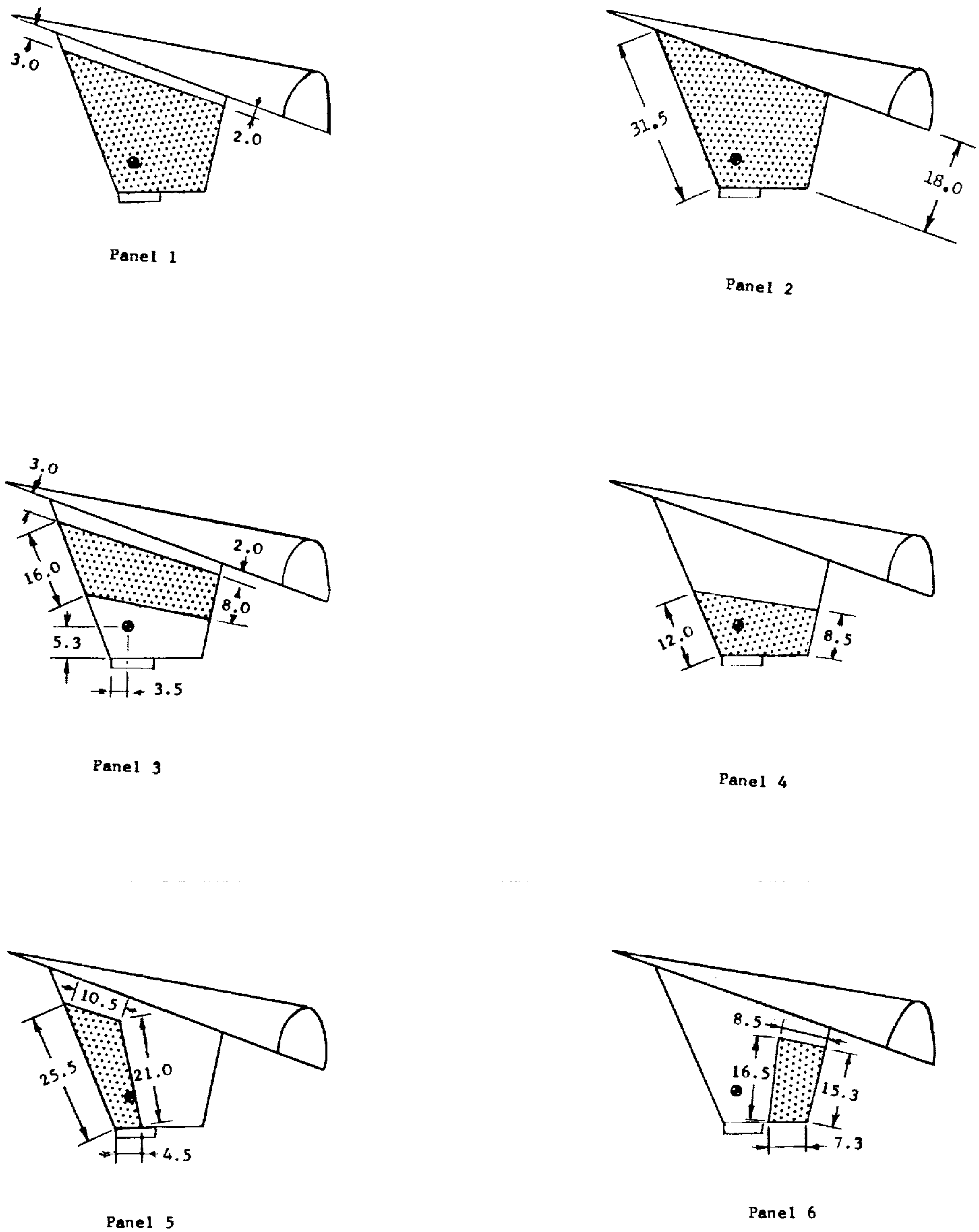
Model

The model used in the investigation was constructed at the Langley Research Center. The wing leading edges and keel consisted of 5-foot lengths of aluminum tubing, 0.75 inch in diameter. The leading edges were fixed at 50° sweep by means of a spreader bar. The fabric was nonporous Mylar bonded to ripstop nylon and had a canopy flat-pattern sweep of 45°. Rigid risers of 0.5-inch-diameter aluminum tubing attached to the leading edges and keel supported an 8-pound steel bar which represented the weight of a payload. Details of the model are given in figure 2 and table I. In its basic configuration the model consisted only of the wing, risers, and steel weight as shown in figure 2(a). It was also provided, however, with the various vertical



(a) Basic configuration.

Figure 2.- Sketch of model used in the tests. All dimensions are in inches.



(b) Panel details. Same center of gravity for all configurations.

Figure 2.- Concluded.

TABLE I.- MASS AND GEOMETRIC CHARACTERISTICS OF THE MODEL

Weight, lb		13.9
Moments of inertia:		
I_X, slug-ft^2		0.77
I_Y, slug-ft^2		0.55
I_Z, slug-ft^2		0.36
Vertical-panel areas, sq ft:		
Panel 1		3.1
Panel 2		3.6
Panel 3		1.9
Panel 4		1.2
Panel 5		1.0
Panel 6		0.9
Wing:	Flat pattern	Flight
Sweep, deg	45	50
Area, sq ft	17.7	16.0
Span, ft	7.1	6.4
Aspect ratio	2.8	2.6
Root chord (keel length), ft	5.0	5.0

panels shown in figure 2(b), which were located beneath the keel in the plane of symmetry.

Test Equipment and Setup

The force tests were conducted in a low-speed tunnel having a 12-foot octagonal test section at the Langley Research Center. The model was sting mounted, and the forces and moments were measured about the body axes by using strain-gage balances.

Flight tests to study the dynamic stability of the model when towed were conducted in the Langley full-scale tunnel with the test setup illustrated in figure 3. A 1/32-inch-diameter aircraft cable towline was attached to the turning vanes ahead of the tunnel contraction. This arrangement resulted in a towline length of 140 feet. An overhead safety cable was used to restrain the model from excessively large motions and was handled by an operator who kept it slack during flight or took up the slack to prevent the model from crashing if its motions became too violent. Motion-picture records were obtained with a camera located at the three-quarter rear location in the test section.

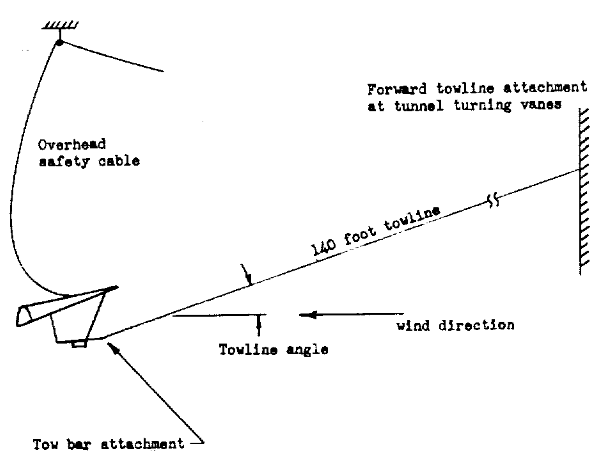


Figure 3.- Test setup used for towing the model.

In this investigation the flights were started with the model hanging on the safety cable. The tunnel speed was then brought up to that required for the particular trim conditions and the model would lift off the safety cable. After the flight behavior had been studied for the required period of time the flight was terminated by decreasing the tunnel speed and taking up the slack in the safety cable.

FLIGHT TESTS

Flight tests were made to determine the dynamic stability characteristics of the model in towed flight. The model was tested in its basic condition and with various vertical panels located in the plane of symmetry beneath the keel. The flights were made at a keel angle of attack of about 20° which corresponds approximately to the angle of attack for maximum lift-drag ratio. The tunnel speed for the tow tests was 24 miles per hour. The towline was attached to the rigid towbar shown in figure 2 so that the towline tension acted approximately through the center of gravity. The effect of towline attachment point was investigated but most of the tests were run with the towline attached at the end of the towbar shown in figure 2.

STABILITY PARAMETERS OF THE MODEL

In order to aid in the interpretation of the flight-test results, force tests were made to determine the static longitudinal and lateral stability characteristics of the model that was flight tested. The tests were run at a dynamic pressure of 1.6 pounds per square foot which corresponds to an airspeed of 37 feet per second at standard sea-level conditions and a test Reynolds number of 1.18×10^{6} based on the keel length of 5 feet.

Static Longitudinal Stability

The static longitudinal stability tests were made for an angle-of-attack range from 15° to 40° for the basic model and for the model with panel 1 on. These data are presented in figure 4 and show virtually no effect of the panel on the longitudinal characteristics, as might be expected.

Static Lateral Stability

The static lateral stability characteristics of the model were determined over a keel angle-of-attack range from 20° to 40° for a sideslip range up to $\pm 20^{\circ}$. The results of these tests are presented in figure 5. These data are summarized in figures 6 and 7 and in the form of the stability derivatives $C_{Y_{\beta}}$, $C_{n_{\beta}}$, and $C_{l_{\beta}}$ plotted against angle of attack. The values of these derivatives were obtained from the difference between the values of the coefficients measured at

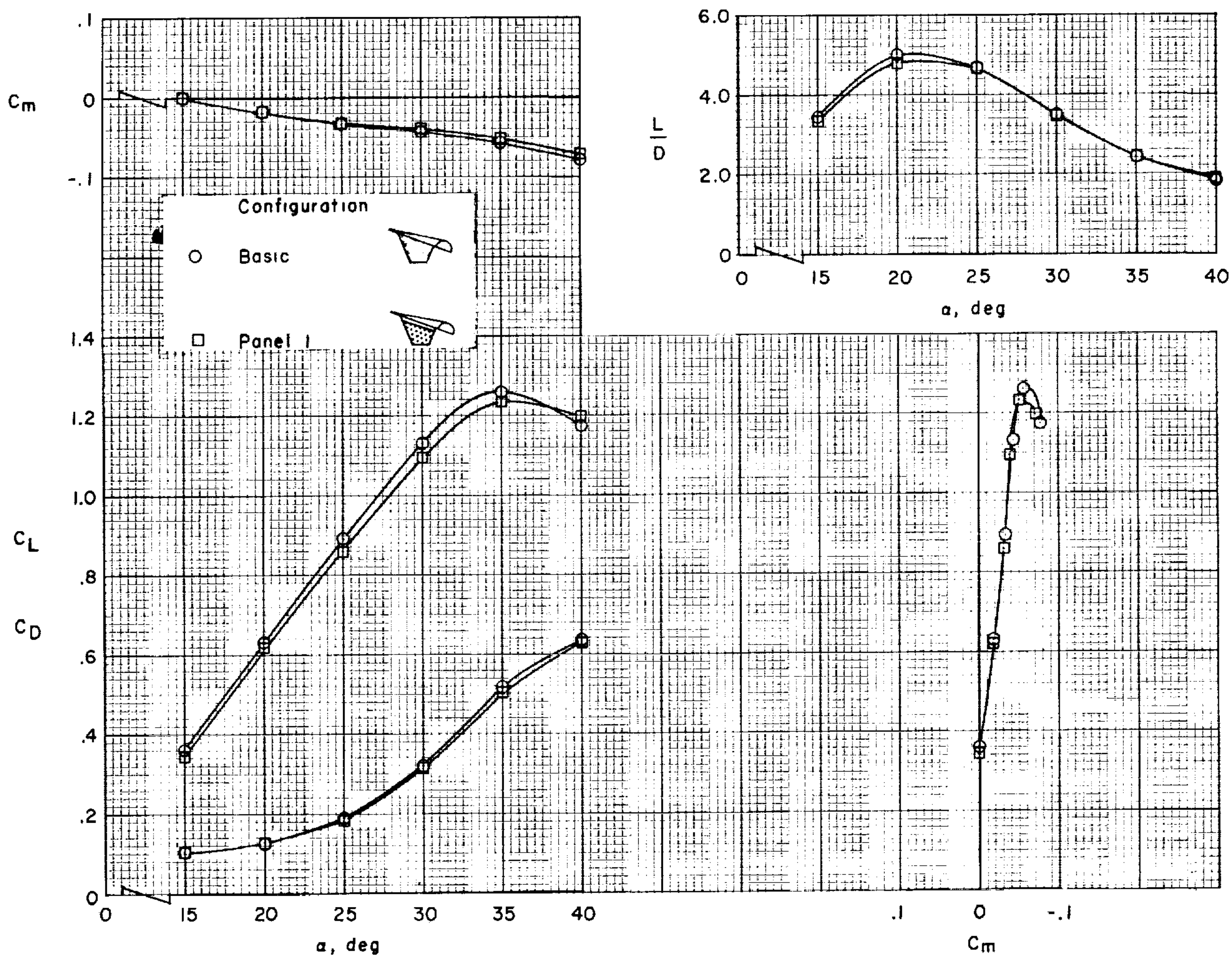
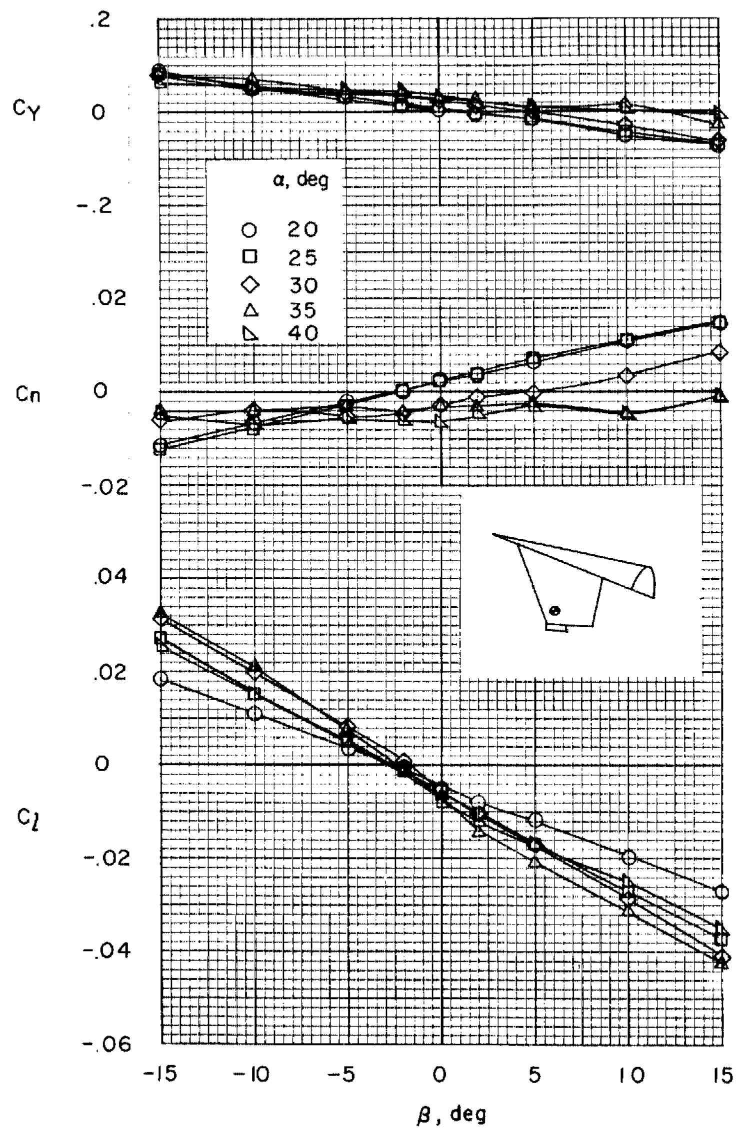


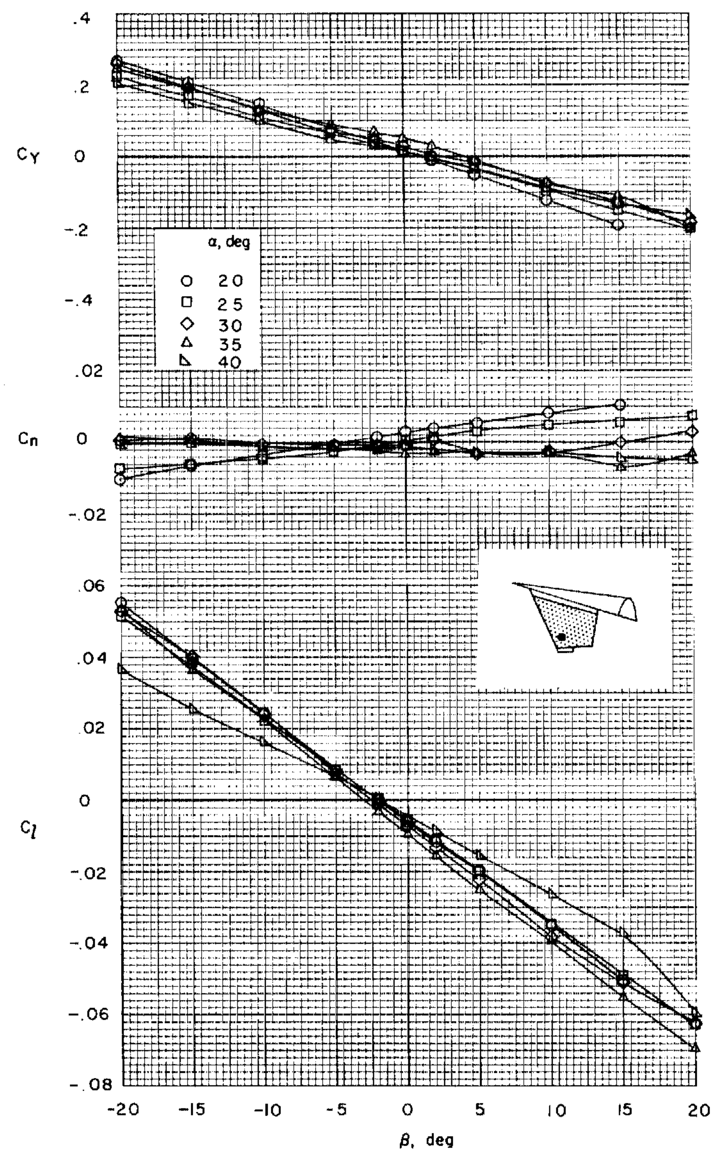
Figure 4.- Longitudinal characteristics of model.

sideslip angles of 5° and -5°. Since the data of figure 5 show nonlinearity at some angles of attack, the derivatives presented in figures 6 and 7 are only used to indicate trends and to provide approximate comparisons of various configurations.

In general, the data of figure 6 show that panels 1 and 2 had some rather large effects on the values of the lateral derivatives. Examination of the panel details presented in figure 2(b) shows that the changes in the derivatives can be accounted for by the changes in the distribution of the panel area with respect to the center of gravity and by the presence of the slot between panel 1 and the wing to reduce the end-plate effect of the wing on the panel. The stability derivatives for the model with panels 1, 3, 4, 5, and 6 on are compared in figure 7 and the effects of the panels are generally those that would be expected.

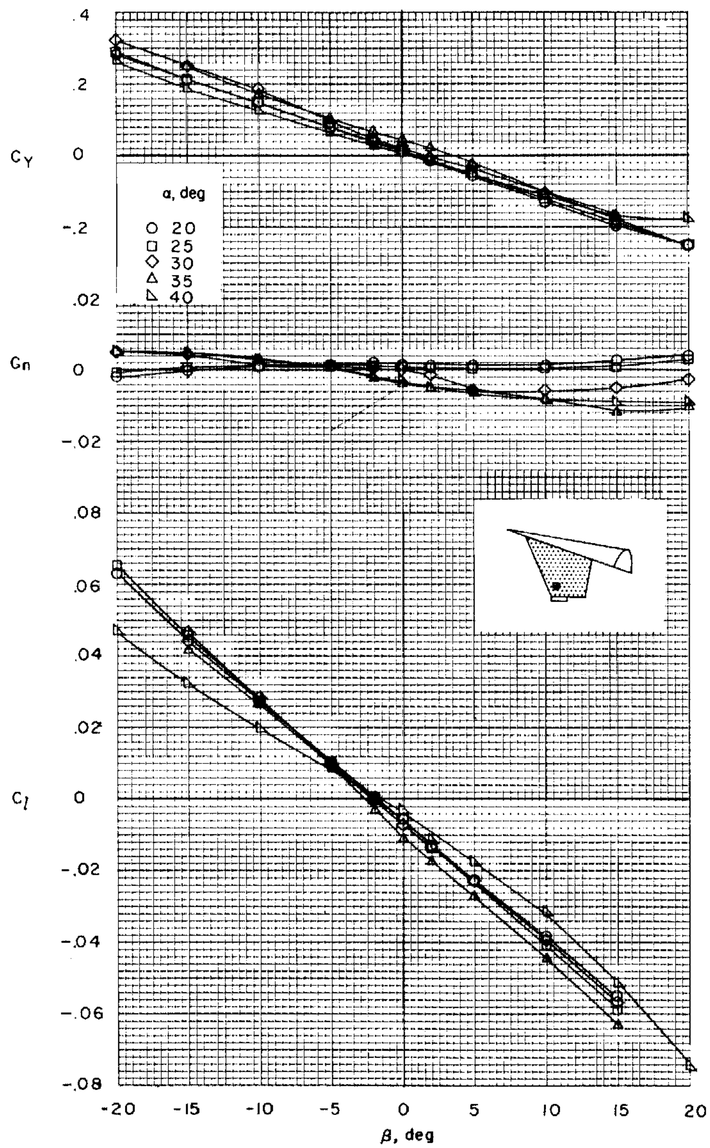


(a) Basic configuration.

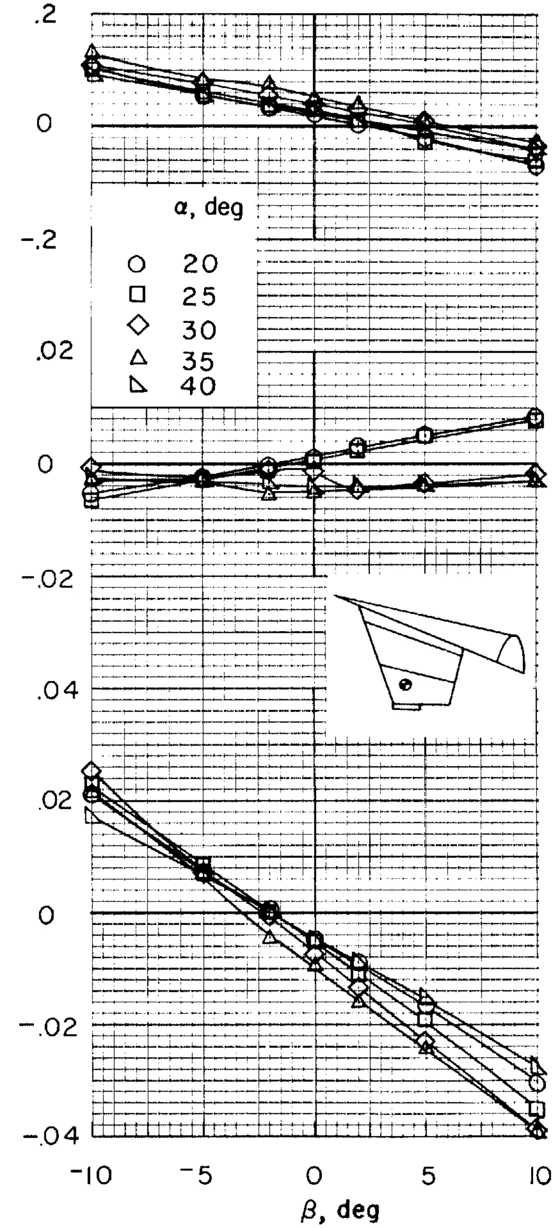


(b) Panel 1.

Figure 5.- Variation of static lateral stability coefficients with angle of attack.

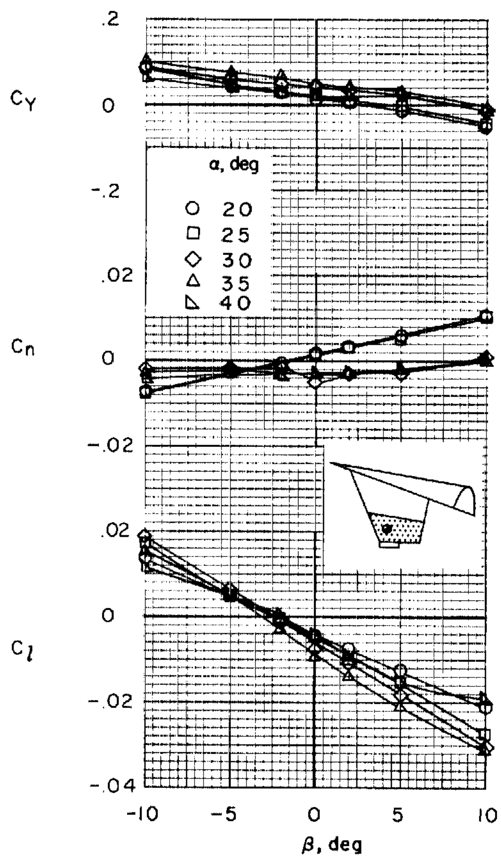


(c) Panel 2.

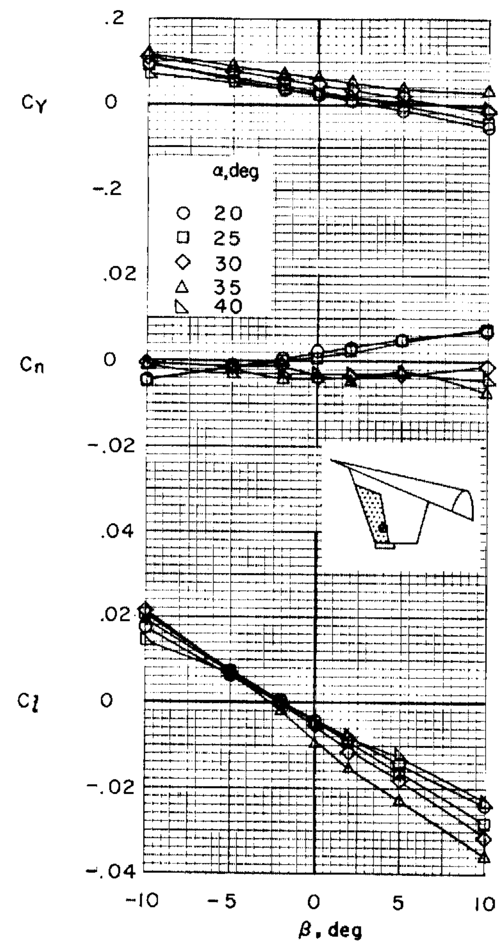


(d) Panel 3.

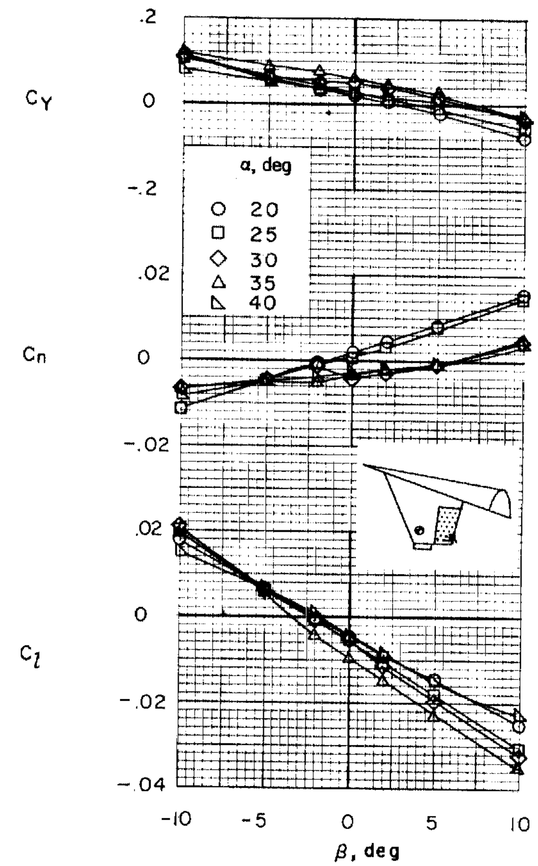
Figure 5.- Continued.



(e) Panel 4.



(f) Panel 5.



(g) Panel 6.

Figure 5. Concluded.

FLIGHT-TEST RESULTS AND DISCUSSION

A motion-picture film supplement covering flight tests of the model has been prepared and is available on loan. A request card form and a description of the film will be found at the back of this paper on the page immediately preceding the abstract and index page.

If the simplified test model was assumed to be 0.25 scale, the model represented a full-scale glider having a keel length of 20 feet, a wing loading of 3.1 pounds per square foot, a tow speed of 48 miles per hour, and a towline length of 560 feet. The scaled-up values presented were obtained by using the dynamic similarity relationships which are summarized in some detail in reference 1.

Basic Configuration

The tow tests showed that the behavior of the model in the basic configuration was unsatisfactory because of a lateral oscillation which usually appeared to be a constant-amplitude (5 or 6 span lengths) lateral translation back and forth across the test section with relatively small amplitudes in roll and yaw. The oscillation was very sensitive to gusts and other disturbances and at various times would appear to be stable, neutrally stable, or unstable depending on the disturbance striking the model. Occasionally, the oscillation would be abruptly damped by a disturbance and the model would appear to be in stable tow for a short time. However, another disturbance would soon trigger the oscillation so that it would build up again and continue for long periods of time. The fact that the oscillation generally appeared to be of relatively large and constant amplitude was taken to indicate that the oscillation was unstable for small amplitudes; and the fact that it was sometimes damped by disturbances and did not build up immediately was taken to indicate that the degree of instability was low.

The longitudinal characteristics were generally satisfactory. There was some vertical movement of the model but the motions were slow and random in nature and of fairly small amplitude (1 or 2 span lengths).

A number of exploratory tests were made in which vertical and horizontal attachment points and towline angle were varied in an effort to improve the towing characteristics. It was found that the best stability was achieved when the towline action was approximately through the center of gravity. Also, the greater the towline angle for the range tested (10° to 15°), with the model lower than the attachment point on the tunnel turning vanes, the easier it was to achieve a stable condition. A large towline angle, however, requires the towing aircraft to operate at a higher power since it must provide a large portion of the lift force for the glider. In this investigation most flights were made with a towline angle of about 12°. Although increasing the towbar length about 50 percent resulted in slightly better stability characteristics, the improvement was not great enough to warrant an extremely long towbar; thus, all subsequent tests were made with the 20-inch (1/3 keel length) towbar shown in figure 2(a).

With the towline attachment point and the towline angle established in this part of the investigation, additional tests were made in which various means were tried in an effort to improve further the lateral stability of the model. From these studies it was found that adding vertical side area in the plane of symmetry beneath the wing could provide a pronounced improvement in the damping of the oscillation, but the location of the area was important. The remainder of the discussion will deal with the effect of area size and location on the lateral stability.

Revised Configurations

Panel 1.- The best lateral stability characteristics were achieved with panel 1. (See fig. 2.) With this configuration the model was generally very steady and there was virtually no translational motion. Occasionally, the model was upset by gusts and disturbances but the damping of the ensuing oscillation was almost deadbeat. The overall characteristics of this configuration were considered to be excellent.

Panel 2.- The lateral stability of the model was greatly changed by the addition of the small strip of area directly beneath the keel that was the only difference between panels 1 and 2. (See fig. 2.) The translational motion was virtually eliminated but a short-period (about 1-second) constant-amplitude, Dutch roll type of oscillation about the towbar attachment point appeared. There was sufficient energy in the oscillation that it was relatively unaffected by gusts and other disturbances; thus there was never any tendency to change the character of the motion. The characteristics of this configuration were considered to be unsatisfactory.

The appearance of the Dutch roll oscillation for the configuration with panel 2 and not for that with panel 1 can probably be explained by the decrease in directional stability $\left(C_{n_\beta}\right)$ and the increase in effective dihedral $\left(-C_{l_\beta}\right)$ (see figs. 6 and 7), derivative changes that greatly reduce the damping of the Dutch roll oscillation of a free-flying airplane. Since it has been pointed out in reference 2 that the addition of a towline to an airplane usually had little effect on the Dutch roll mode, it appears that the Dutch roll oscillation experienced for the panel 2 configuration was due to the change in C_{n_β} and $-C_{l_\beta}$.

Panels 3 and 4.- When the side area of the vertical panel was reduced considerably from that of panel 1 to that of panels 3 and 4, the lateral motions of the model were generally similar to those of the basic configuration although the motion was lightly damped and there were longer periods of steady flight than with the basic configuration.

Panels 5 and 6.- A reduction in the side area in the fore-and-aft direction did not result in satisfactory tow characteristics but the behavior of the model varied greatly with location of the side area, evidently because of differences

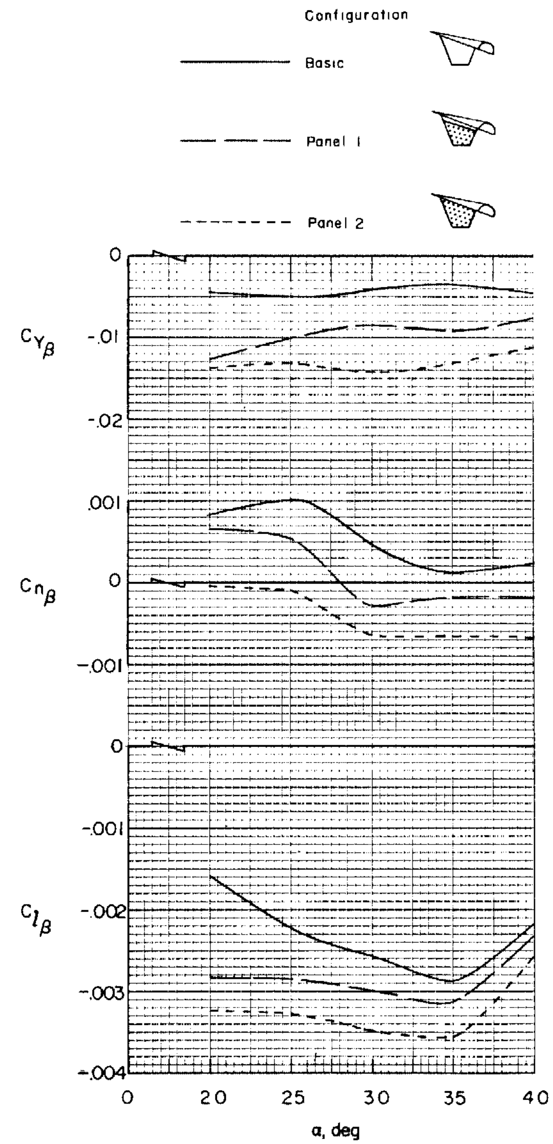


Figure 6.- Variation of static lateral stability derivatives with angle of attack. Basic configuration and panels 1 and 2.

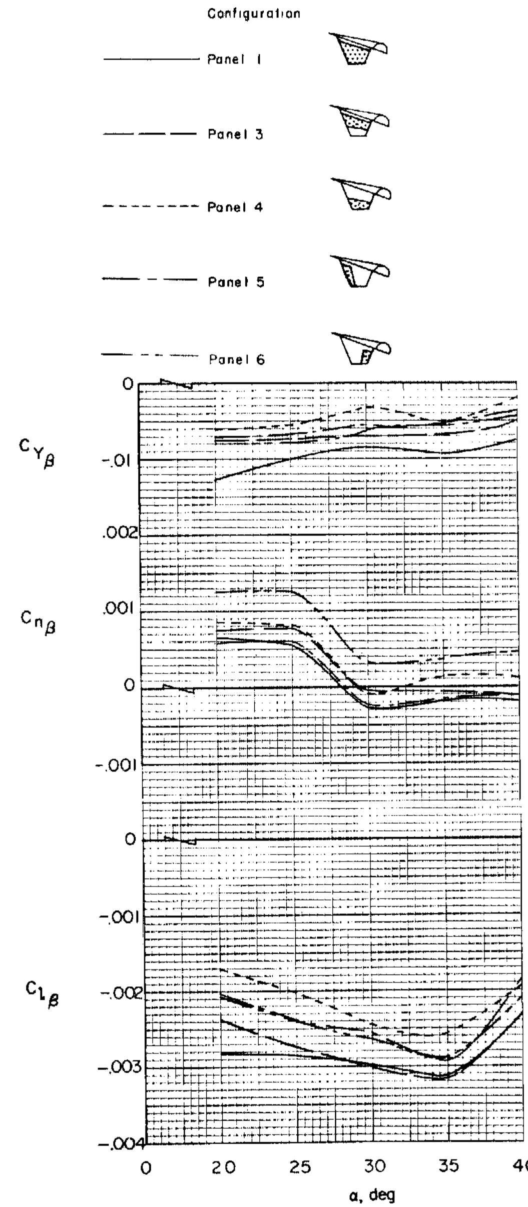


Figure 7.- Variation of static lateral stability derivatives with angle of attack. Panels 1, 3, 4, 5, and 6.

in directional stability between panels 5 and 6. With panel 5 the tow characteristics were actually fairly good. The model had a tendency toward a lateral oscillation similar to that of the basic configuration but there was definitely a damping tendency at times and long periods of steady flight. With panel 6, however, the model had the large constant-amplitude oscillation characteristic of the basic configuration. In fact, the oscillation appeared to be worse because it never damped out. Also, the model had a strong weathercock tendency, because of the increased directional stability, which resulted in considerable yawing displacement of the model about the towbar attachment point during translation.

CONCLUDING REMARKS

An investigation in the Langley full-scale tunnel to study the tow characteristics of a parawing glider indicated that the basic configuration (wing, risers, and a steel weight representing a payload) was unsatisfactory because of a constant-amplitude lateral oscillation which appeared mainly as sidewise motion. It was found that the addition of vertical side area in the plane of symmetry beneath the wing made the tow characteristics satisfactory, if the area was properly located. It should be pointed out that in this investigation the model did not have a cargo package of any appreciable dimensions and that, therefore, only the aerodynamics of the wing and vertical panels were involved. For other configurations and angles of attack, a somewhat different arrangement of side area might be necessary to achieve satisfactory tow.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., November 28, 1962.

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